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Hygrothermal behaviour of compact roofs under Belgian climate

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ABSTRACT

Compact flat roofs are more and more constructed in Belgium due to their limited thickness allowing slender roofs with high thermal performance. In this roof type the insulation layer is situated in between the wooden rafters with the roofing membrane directly above on a wooden support structure. Due to this composition the condensation plane is located at the support structure of the roofing membrane. Thus, an increased risk of degradation is present as compared to a typical flat roof system where the insulation is placed on top of the structure. Generally, to account for this a moisture-dependent vapour retarder is used in combination with a hygroscopic capillary-active insulation material, typically cellulose. It remains unclear though how hygroscopic non-capillary active insulation materials influence the hygric response of the roof, what the influence of the initial moisture content and type of underlay is and what impact degradation of the roofing membrane has on the hygric stability of the construction over time. Therefore, a field test consisting of 4 compact roofs insulated with cellulose and 4 compact roofs with woodwool insulation, all covering a bathroom, was performed. The interior vapour barrier was varied between OSB sheeting, 2 moisture dependent vapour retarders and a PE barrier. Measurements were made both on the material properties and on the moisture content of the wooden support. Comparison with hygrothermal simulations using WUFI showed the importance of airtightness and achieving a specific density of the blown-in insulation material as well as avoiding air pockets around the wood pin sensors. Woodwool insulation was found to render a high risk on woodrot as compared to the safer spray-in-place polyurethane, mineral wool and blown-in cellulose. The simulations clearly show the importance of avoiding water trapping during construction. Soiling of the roofing membrane was found to have a minor influence on the hygrothermal safety. On the contrary, degradation of the roofing membrane leading to leakage into the structure was found to lead to conditions favourable of rotting of the OSB sheeting.

KEYWORDS: Compact flat roof, field test, HAM, wood frame construction, WUFI
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1 INTRODUCTION

The application of compact roofs remains a point of discussion in Belgium due to the potential hygrothermal risks. In current practice the use of warm type flat roofs, in which a rigid insulation layer is placed on top of the structural wooden rafters is preferred. The roofing membrane is supported directly by the dense insulation layer, effectively eliminating degradation prone materials from condensing locations. Due to tighter legislation increasingly larger insulation thicknesses are required, leading to a larger total thickness of the roof system. In contrast to this, compact roofs are insulated in between the wooden rafters. This allows for more slender roofs without compromising insulation quality. The insulation is most commonly blown in place cellulose, the roofing membrane is typically supported by wooden planking or OSB. Hygrothermally, the shift of the insulation layer from outside in warm roofs to in between the wooden rafters in compact roofs entails risks as the potential condensation plane is situated at the wooden support structure, increasing the risk of woodrot.

Previous studies [1, 2] have already shown the potential of hygroscopic and capillary active materials such as cellulose to actively buffer moisture diffusing into the compact roof, thereby reducing the risk on condensation. In addition, moisture adaptive vapour barriers allow regulating the accumulation and drying rate of moisture in the roof. Due to their variability in water vapour diffusion coefficient relative to the local relative humidity, they allow the moisture accumulated during winter periods, when the moisture flux is outward, to dry out in summer periods when the moisture flux is directed inwards due to the increased solar irradiation. Nevertheless, it remains critical to avoid convective moisture transport [3], necessitating the need for very good airtightness. Typically this is achieved by meticulously sealing the vapour barrier, convective moisture transport within the cellulose layer is avoided by ensuring a set density.

Overall, the main focus of previous research work was on the dynamics and application of hygroscopic and capillary active insulation such as cellulose in combination with moisture adaptive vapour barriers. It remains unclear though how hygroscopic non-capillary active insulation materials, such as wood wool insulation, and non-hygroscopic, non-capillary active insulation materials, such as mineral wool, influence the moisture safety of the roof. Additionally, there is a need for information on the influence of the initial moisture content of the structural members on the hygrothermal safety and on the influence of ageing of the roofing membrane on the drying-out capacity of the compact roof.

2 In situ measurements

Measurements were performed on a compact roof located at Ronse, Belgium. These measurements were used to calibrate the WUFI simulation model for compact roofs under the given configuration and climate. The roof was divided in 8 separate entities each with a different type of insulation material and vapour barrier. The configuration of the roof is shown in Figure 1, together with the material properties in Table 1. Careful attention was given to the airtightness of each separate entity to avoid convective shortcutting of moisture and heat flows.

On the inside the compact roof was subjected to a humid climate as shown in Figure 2. This climate was achieved by both heating with a setpoint of 23 °C and humidifying with a setpoint of 73 % relative humidity. Measurements of the exterior climate were performed on site for the relative humidity and temperature, data on solar radiation was gained from the Royal Meteorological Institute of Belgium (KMI).

Each compartment of the compact roof was equipped with a thermocouple for temperature measurements and a relative humidity sensor at the top of the insulation, and wood pins for the local moisture measurements. The wood pins were inserted into the OSB layer, attention was given to attain a distance of 15 mm between the two pins. Sensor locations are shown in Figure 1. Langmans [3] pointed out the importance of avoiding air pockets around wood pins to increase accuracy, yet due to the blowing process no information on the actual coverage is available.

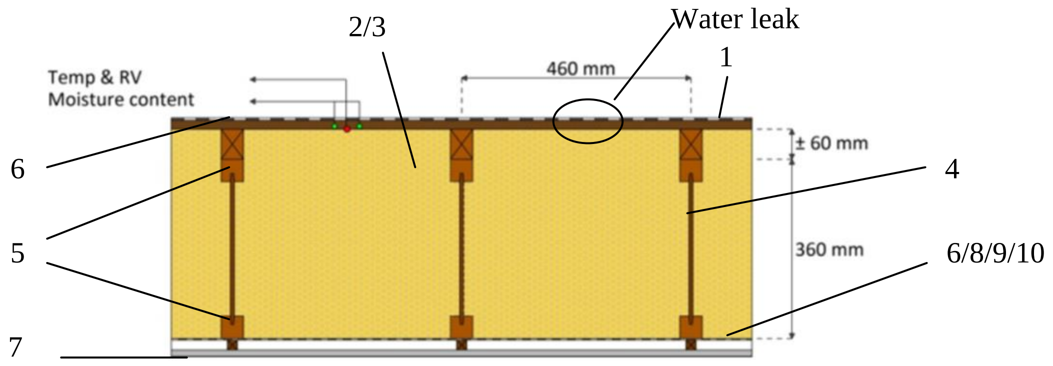

Figure 1. Setup of 2 compartments of the compact roof at Ronse

Table 1. Material properties and numbering of the in-situ compact roof compartments

	Material	λ W/mK	μ -	Measured A $kg/m^2s^{0.5}$	ρ kg/m^3	c J/kgK	Porosity -	Ref. moist. content kg/m^3	Wcap kg/m^3
1	roof membrane	0.16	15000 (1mm)		1000	1500	0.0002		
2	Woodwool	0.038	1.5	0.1067	35	2100	0.95	9.04	430
3	Cellulose	0.039	1.5	0.1067	45	2150	0.95	5.97	233
4	Hardwood Fibreboard	0.05	10		900	1700	0.8		
5	Pine	0.13	50		510	1600	0.73		
6	OSB	0.12	150		560	1700	0.65		
7	Gypsum	0.2	8.3		850	850	0.65		
8	DB+	2.3	4350 (1mm)		156	2300	0.086		
9	Intello +	2.3	16500 (1mm)		110	2300	0.086		
10	PE-Foil	2.3	10000 (1mm)		130	2300	0.001		

Compartment	DB+	Intello +	OSB	PE- foil
Woodwool	1	5	3	7
Cellulose	2	6	4	8

Measurement results are reported in figure 3. A clear distinction can be seen in the measured relative humidities for sensors 1-4 and 5-8. Most likely, this can be related to damaging of the sensors, in the following only the measurements of the wood moisture content using woodpins are used. The temperature measurements give good agreement for the different compartments as they are mainly dominated by the outside conditions. The wood moisture content measurements show a general drying out of the roof in time. In the case of woodwool insulation (Woodpin 1, 3, 5, 7) higher moisture contents of the supporting wood structure are found than in the compartments with cellulose insulation, indicating a higher moisture buffering effect for the latter than the former.

3 Modelling

3.1 Model validation

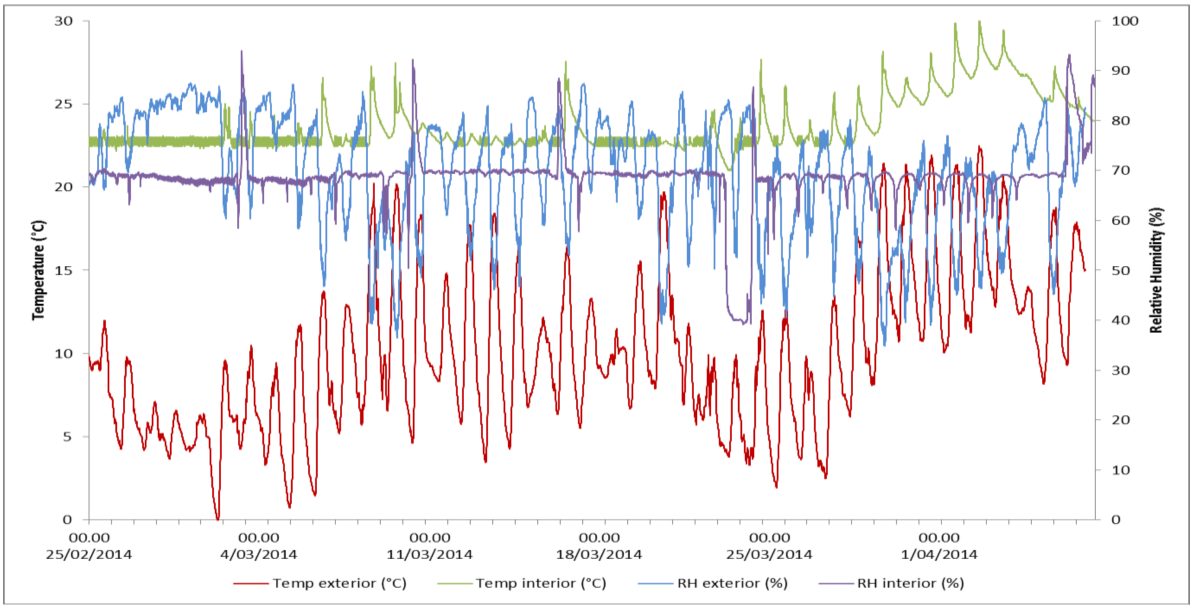

Figure 2. In-situ exterior and interior temperature and relative humidity measurements

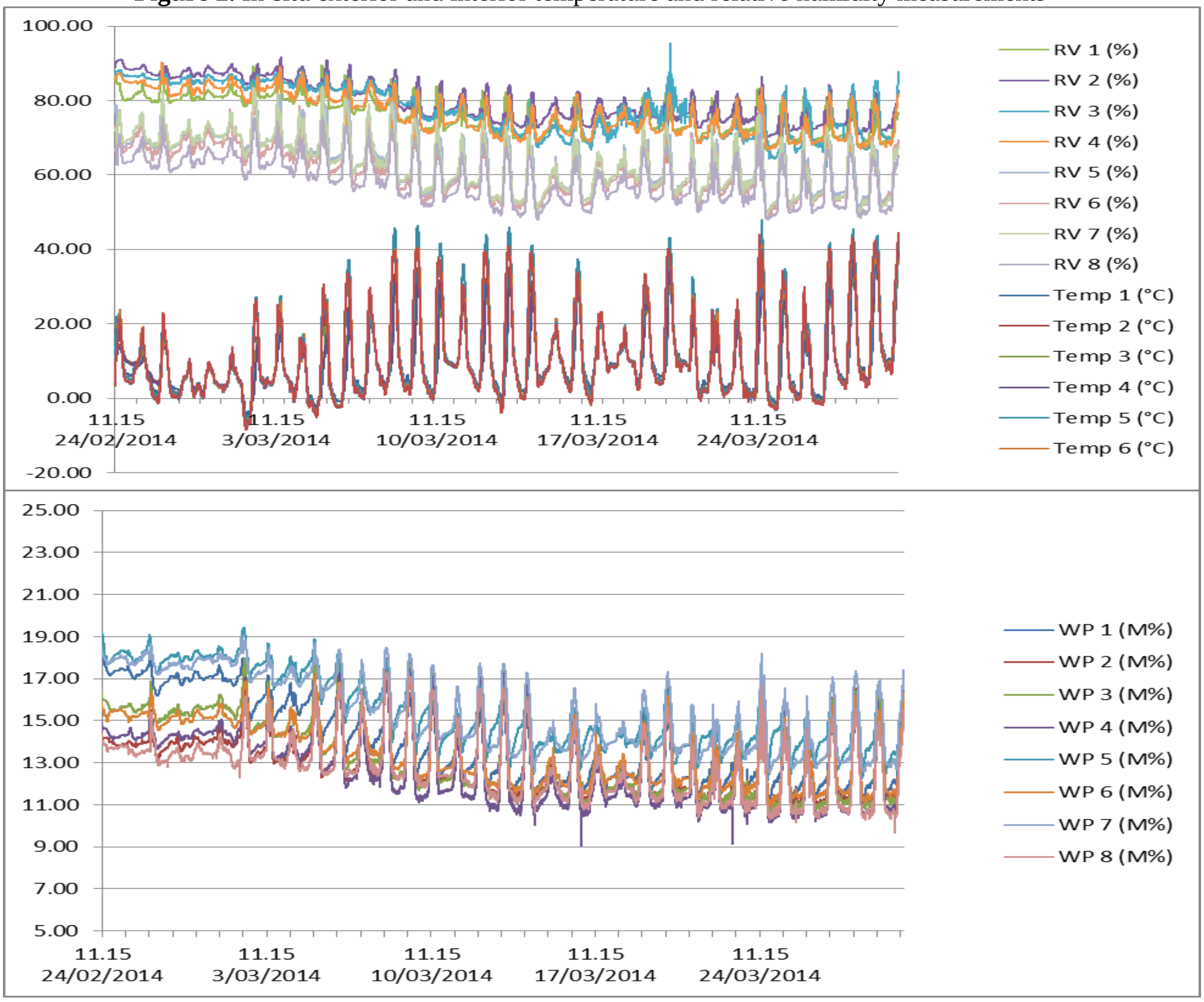

Figure 3. Above: measured temperature and relative humidity of the OSB sheeting for the different compact roof compartments, below: measured moisture content of the OSB sheeting using woodpins (M% kg/kg)

Based on the measured weather and material data a validation of the hygrothermal model was performed. Due to the use of extrapolated solar radiation data from a nearby weather station, a validation was only performed for the period of 7/03 to 15/03/2014, for which the best agreement was found between measured and simulated temperature of the OSB underlay. All simulations were run using WUFI 2D 3.3.

Figure 4 shows a comparison between measured and simulated wood moisture content and temperature of the OSB support structure for the roofing membrane. Overall, the general trend of accumulation and drying out is observed. For the cases with woodwool insulation (uneven compartment numbers) a good agreement was found between simulation and measurement. However, upon close analysis differences in moisture content can be observed between simulation and measurement. One possible explanation could be the occurrence of air pockets around the wood pins, which can lead to significant measurement errors due to local convective loops [3], another explanation the occurrence of convective loops through the compact roof and within the insulation layer which are not accounted for in the model. As no information is available on the airtightness of the roof, perfect airtightness was assumed in the model. Additional simulations were run using WUFI 1D for compartment 2 with cellulose insulation to assess the importance of potential air leaks. Leakage of internal air at 1 m^3/h was assumed in the model, mixing with air present at a 5mm gap above the insulation layer. It was found that adding infiltration leads to higher moisture contents of the OSB sheeting, but no similar patterns as observed in the measurements were found.

3.2 Case studies

To evaluate the hygrothermal behaviour of compact roofs, simulations were performed on the influence of the type of insulation material, the initial moisture content of the wooden support structure and the degradation in time of the roofing membrane. All simulations were run using the same configuration as above for a period of 3 years using a weather file for Brussels on the exterior, and a constant interior climate of 23°C and 60% R.H. replicating a typical bathroom climate. All materials are at an initial RH of 80%.

3.2.1 Insulation material

Currently hygroscopic capillary active insulation materials, such as cellulose, are actively promoted for use in compact roofs. It remains unclear though whether hygroscopic, non-capillary active materials such as woodwool provide hygrothermal safety as well. Additionally, the use of polyurethane and mineral wool was evaluated using the materials found in the WUFI database. The simulations are run using the DB+ vapour barrier on the interior. Figure 5 shows the moisture content of the OSB sheeting, it can clearly be seen that woodwool insulation leads to excessive moisture contents above 20M%, the threshold for degradation of wooden structures. Although cellulose insulation has a clear buffering effect and remains under the threshold of 20M%, sprayed polyurethane insulation performs consistently better. This is most likely to its high µ-value in relation to the µ-value of cellulose insulation limiting moisture to diffuse in the structure. Overall all insulation materials show a drying-out behaviour in time.

3.2.2. Initial moisture content and type of underlay

Typically, compact roofs are constructed using OSB sheeting or wooden planking to support the roofing membrane. However, during construction rainwater can wet these components leading to an increase of the initial moisture content. To evaluate the importance of this parameter simulations were run using different initial moisture contents for the OSB sheeting and Pine planking, 12M% for dry conditions, 18M% for the wetted conditions. In addition, an evaluation against non-degradable fibre cement boards was performed. The compact roof was insulated with blown-in cellulose insulation and covered with a DB+ vapour barrier. Figure 6 shows that under the indoor climate of 23°C and 60% R.H. pine planking remains above the critical moisture content of 20M% for extended periods of time, for both initial conditions. In the case of an OSB underlay the effect of increased initial moisture content is less prevalent. Due to its different sorption curve fibre cement board both shows lower overall moisture content and an overall more stable moisture content.

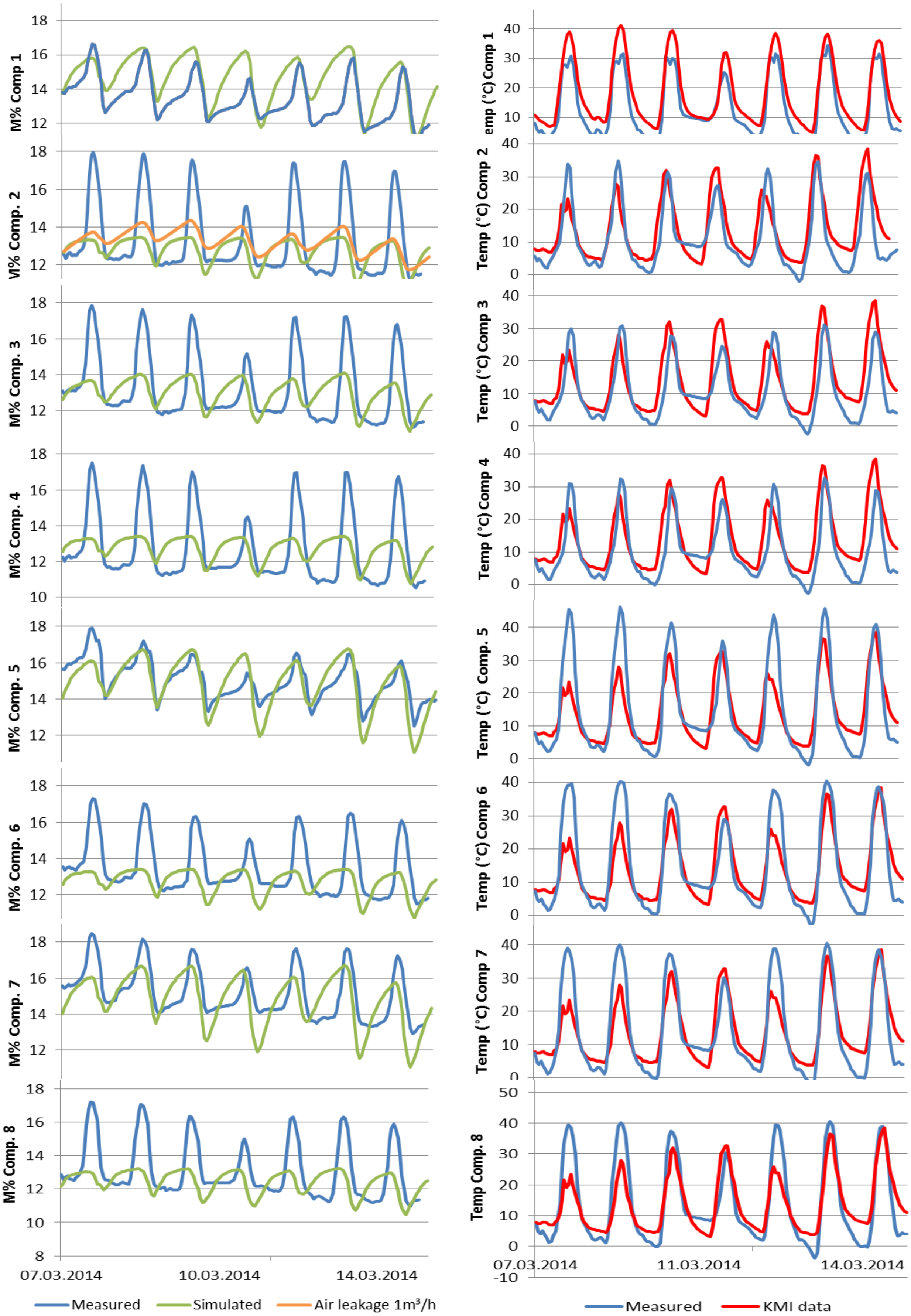

Figure 4. Comparison between measured and simulated moisture contents and temperatures of the OSB sheeting

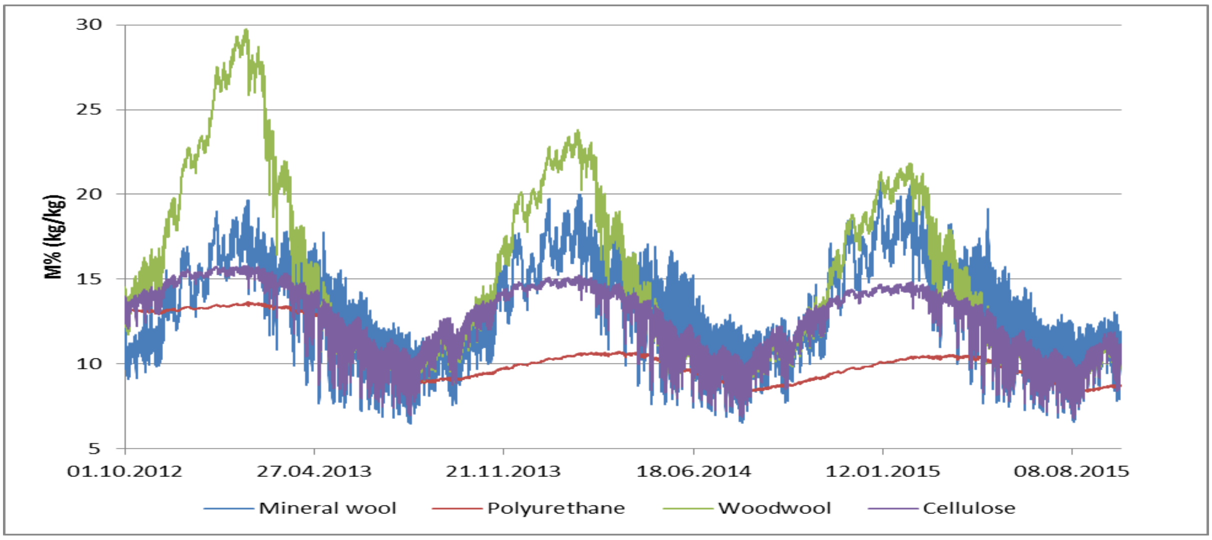

Figure 5. Simulated moisture contents of the OSB sheeting for different insulation materials

3.2.3. Degradation of the roofing membrane

Roofing membranes are prone to two types of degradation: change in absorption factor of the exterior surface due to solar irradiation, and water leaks. Changes in the colour of the membrane can lead to reduced drying potential during summer periods, leading to accumulation of condensate over time, water leaks can bring large amounts of water in the compact roof. Simulations were performed on both parameters, for the latter by including infiltration amounting to 1% of the rain, for the former by reducing the solar absorption coefficient of the membrane from 0.87 for black, matt roofing to 0.86 for soiled, green roofing. The effect of light coloured roofing was studies using a solar absorption coefficient of 0.5. The location of rainwater penetration is given in Figure 1 . The moisture content of the OSB sheeting is determined at the same location.

The simulation results in Figure 7 show that soiling of the roofing membrane has a relative limited effect on the moisture content of the OSB sheeting. Using light coloured membranes leads to higher moisture contents in the OSB sheeting, whereas the darker coloured membranes lead to drying out of the sheeting. Due to the local penetration of liquid water very high relative humidities for extended periods of time can be found that will lead both to woodrot and redistribution in the compact roof due to dripping.

4 Conclusions

Based on in situ measurements in Ronse the WUFI 2D model was further validated for compact roofs insulated with woodwool insulation, allowing to predict the hygrothermal behaviour under Belgian climate. In comparing the simulations with the measurements for cellulose it is found that several factors can influence the measurement results, such as local air pockets and convective looping, a factor that is unaccounted for in the model. Uncertainties related to the nature of the climatic data and material data further influence the result. Overall though, the global hygrothermal trend of the compact roof with woodwool insulation can be simulated accurately.
Simulations were performed on the influence of the insulation material, initial moisture content and type of support structure, and the influence of ageing of the bituminous membrane on the hygrothermal safety of the compact roof. For the insulation material it was found that woodwool insulation does not provide a hygrothermal safe construction, whereas blown-in cellulose, mineral wool and polyurethane insulations lead to moisture contents of the OSB sheeting below the critical wood moisture content for woodrot of 20M%. Higher initial moisture contents lead to longer periods of high wood moisture contents, potentially increasing the risk on degradation. However, it was

found that both OSB sheeting of fibre cement boards both provide hygrothermal safe constructions, as compared to pine planking. Soiling of the roofing membrane was found to have little effect on the hygrothermal safety of the compact roof. Light coloured membranes increase the risk on degradation. Additionally it was found that water leaks into the structure due to ageing of the roofing membrane can lead to high moisture contents for prolonged periods of time, increasing the risk on degradation of the wooden support structure.

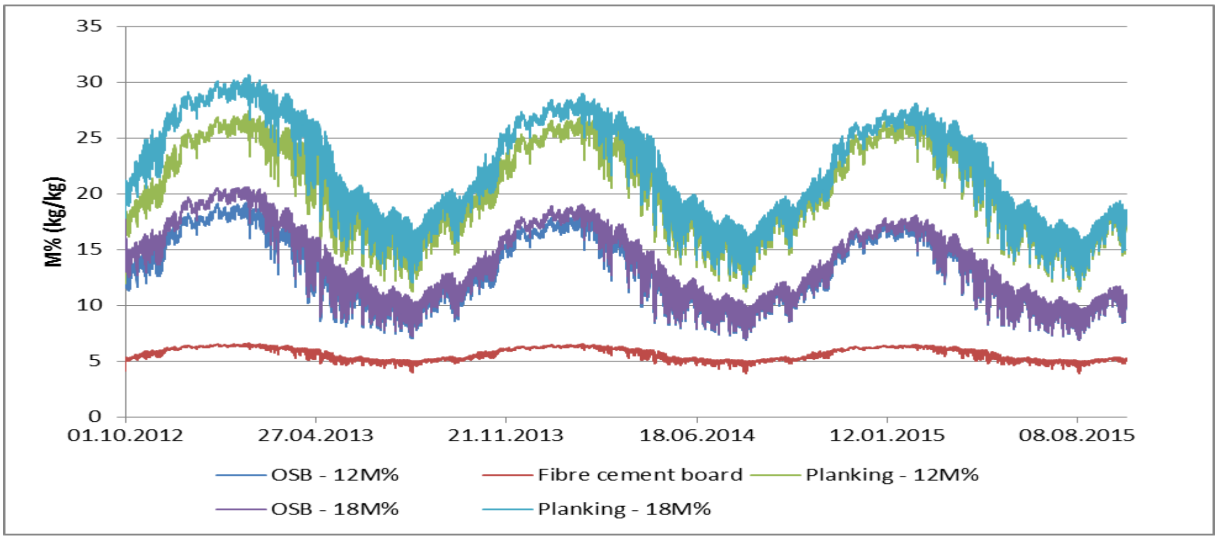

Figure 6. Simulated moisture contents of the roofing membrane support structure for different materials and initial moisture contents

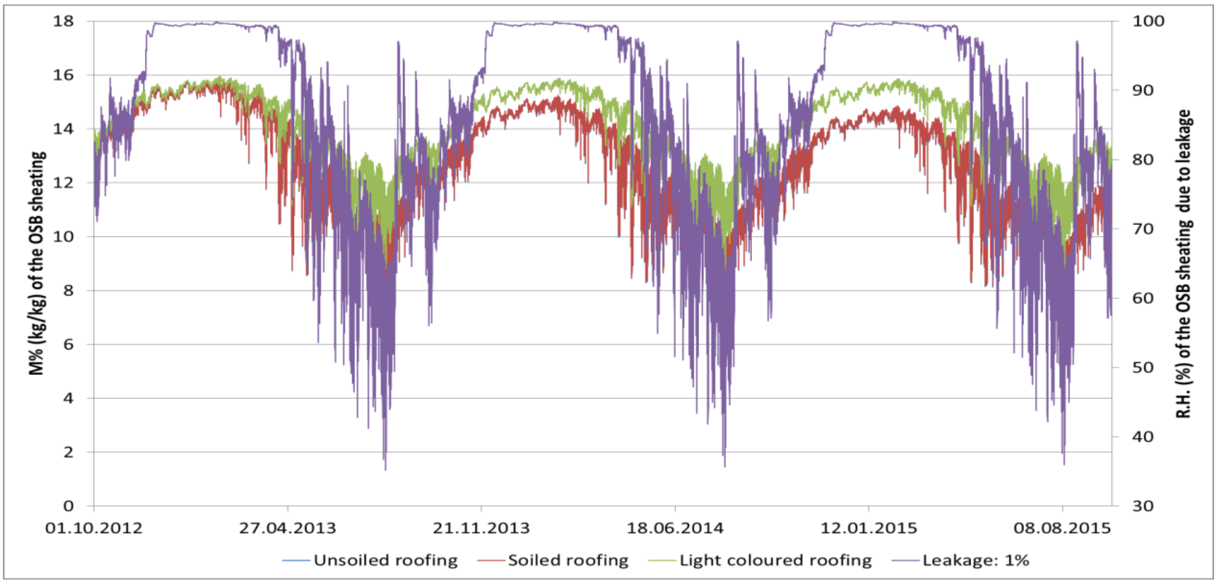

Figure 7. Left: Moisture content (M% kg/kg) of the OSB sheeting for soiled and unsoiled roofing membranes. Right: local relative humidity of the OSB sheeting in case of a 1% rain leakage

REFERENCES

1. Derome, D., *Moisture occurence in roof assemblies containing moisture storing insulation and its impact on the durability of building envelope*, in *Department of Building, Civil and Environmental Engineering*. 1999, Concordia University.
2. Geving, S. and J. Holme, *The drying potential and risk for mold growth in compact wood frame roofs with built-in moisture.* Journal of Building Physics, 2010. **33**: p. 249-269.
3. Langmans, J., *Feasibility of exterior air barriers in timber frame construction*, in *Faculteit Ingenieurswetenschappen Departement burgelijke bouwkunde afdeling bouwfysica*. 2013, KU Leuven: Leuven.